Project Final Report

I. Report Title, Author, Organization, Grant Number, Date

Evaluation of LiftUp® system in the mitigation of environmental impacts and fish health in net-pen aquaculture

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Project ID: FNA03NMF4270151

March 9, 2006

II. Abstract

A brief (one paragraph) description of the Final Report (for use in the S-K Annotated Bibliography).

Benthic conditions under Atlantic salmon fish pens equipped with LiftUp® technology were tested against standard pens at a commercial salmon farm in Maine. The goal of the project was to determine whether or not use of LiftUp®, which was designed to remove dead or moribund fish without the need for a diver, could also effectively mitigate or reduce organic loading to the bottom. This project compared benthic conditions under standard and LiftUp®-equipped pens and at two far field sites for two growing seasons. Effluent water quality was also examined and fish health parameters measured. Results show that while LiftUp® does generally reduce loading to the bottom, the differences between the LiftUp® and non- LiftUp® systems were not statistically significant; impact to ambient water quality from operating the system are minimal. No differences in fish health meristics were observed between standard and LiftUp®-equipped systems.

III. Executive Summary

A brief and succinct summary of Final Report.

LiftUp® technology was evaluated for its possible use in the mitigation of environmental impacts and fish health management at a commercial salmon growout facility in Machias Bay, Machiasport, Maine operated by Atlantic Salmon of Maine LLC. Four treatments, LiftUp®-equipped cages, standard cages, 30m distance from cages (regulatory compliance boundary distance), and a reference site were compared using biological and sediment chemistry metrics to measure organic enrichments and environmental degradation. Quality of the water within the LiftUp®-equipped and standard cages, as well as the LiftUp® discharge, were also measured. Additionally, fish health was evaluated for both LiftUp®-equipped and standard cages using measures of growth and mortality, clinical evaluation during routine veterinary site inspections, and periodic measures of packed cell volumes and white cell counts from subsets of apparently healthy fish; evaluation of potential impacts to pathogen exposure pathways was done using stable isotope concentrations as a measure of exposure to fish carcass or excretory products.

No statistically significant differences were seen between the LiftUp® and non-LiftUp® cages at the end of the project; early in the project, statistically significant differences were seen for certain parameters. Nevertheless, consistently lower states of organic enrichment were observed under the LiftUp® cages compared to the non-LiftUp® cages based on both benthic infauna and sediment chemistry results. No statistically significant differences in standard fish health metrics were noted between LiftUp® and diver-based mortality recovery systems. However, significant differences in isotopic composition of fecal material (and trends in fish growth) raise questions about alterations in diet. Dissolved and particulate material resulting from LiftUp® operation surface discharge does not raise environmental concerns due to its brevity (<100 seconds), very small area (5m x 10m oval), and intermittent frequency (1-3 times per week); however, surface discharge does raise concern over spread of disease during presence of infection or parasites.

Clogging of the china hats, due at least in part to freeze-up in winter, appears to have been the most influential/confounding factor in obscuring differences between LiftUp® and non-LiftUp® cages over the course of the project. Sediment grain size shift toward coarser material at all sampling stations was not expected, and is unexplained at the moment. This sediment grain size shift may also have contributed to obscuring differences between LiftUp® and non-LiftUp® cages.

Overall, and with several strong caveats, this project demonstrated that LiftUp® type technology may offer some potential environmental benefits for a very specific selection of site-types. However, it is unclear whether those same benefits can be achieved more cost-effectively through employment of traditional best management husbandry since environmental conditions under the non-LiftUp® pens generally remained within legal standards set forth in the MePDES permit throughout the project period. Use of LiftUp® type technology is not possible under sub-freezing conditions, in areas shallower than 65 ft. at low water, or at high energy sites and may not be warranted even under slower current regimes. LiftUp® is clearly neither warranted nor practicable at all sites and its applicability in Maine may be limited to very specific circumstances.

IV. Purpose

A. Detailed description of problem or impediment of fishing industry that was addressed.

Environmental impacts to the bottom beneath and adjacent to salmon aquaculture cages have been well documented. Sites located over soft, mud bottom with low current velocities are generally more vulnerable to benthic loading. To meet environmental standards, some existing operations find compliance difficult at historical rates of production. Availability of new sites is greatly limited by existing users of the water as well as opposition from shorefront property owners. To insure that existing sites with demonstrated susceptibility to environmental degradation can continue to be operated in compliance with current and emerging environmental standards and/or to develop new opportunities at lower energy soft-bottom sites, measures must be developed to reduce the amount of waste discharged to the bottom without compromising water quality or fish health.

LiftUp® is a technology originally designed to facilitate collection of fish mortalities in net pens. Traditionally, divers provided this service. However, diver collection has operational disadvantages. Use of divers inside nets can be hazardous, can slow fish growth by putting them off feed, is weather dependent, is thought to be a potential source of exposure to disease transmission, and competes for time from facility staff.

LiftUp® consists of a conical pen bottom on which large solids such as dead or moribund fish and large feed pellets collect and fall to a centralized point. At the center is a flexible tube into which air is injected thereby creating an airlift. Material collected on the bottom is lifted up and out of the pen.

While the device has been used successfully to remove large solids, we hypothesized that by using a finer mesh bottom panel, this same technology might reduce the amount of waste falling to the sea floor and thus either increasing the holding capacity of a farm site or reducing wastes at a site that is causing unacceptable benthic impacts.

In addition to the immediate question around the effect of LiftUp® on benthic loading, we were also concerned about exchanging one problem for another. Resuspending waste feed and feces and discharging it to the water column has the potential to degrade water quality. This is not merely an environmental concern, but also one of fish health; wastes reintroduced into the water column also could result in exposing healthy fish to pathogens associated with dead or moribund fish.

B. Objectives of the project.

Three objectives (hypotheses) were identified in this project:

1. to assess feasibility of LiftUp® as a means to reduce environmental impact under commercial salmon pens.
2. to assess potential water quality impacts caused by LiftUp® operation.
3. to assess effect of LiftUp® on fish health.

V. Approach

A. Detailed description of the work that was performed.

See VI. Findings below and Final Technical Report – Appendix A for details.

B. Project management: List individuals and/or organizations actually performing the work and how it was done.

Christopher S. Heinig, MER Assessment Corporation: Co-PI and overall coordinator for the project, data compilation and analysis, and co-authorship of the final technical report;
John Sowles, Maine Department of Marine Resources: Co-PI, water quality sampling, overall statistical analysis of environmental results, and co-authorship of the final technical report;
Lori Gustafson, U.S. Department of Agriculture: fish health assessment, isotope results analysis, and co-authorship of the final technical report;
David Miller, Atlantic Salmon of Maine LLC: project oversight for ASM, production data compilation;
Jon Lewis and Marcy Nelson: Maine Department of Marine Resources, project divers for sample collection;
Brian Tarbox, James Reidy, and James Berke: contract project divers for sample collection;
Daniel Millar and Steven Karpiak: MER Assessment Corporation, on-site sample processing, redox and sulfide measurements, and benthic sample sorting and identification;
S.W. Cole Engineering, Inc., Gray, Maine: granulometric analysis;
Linda Schick, Darling Marine Center, University of Maine, Walpole: Total organic carbon analysis;
See Final Technical Report for specific sampling and analytical methods.

VI. Findings

A. Actual accomplishments and findings.

Accomplishments

Four treatments, LiftUp®-equipped cages, standard cages, 30m distance from cages (regulatory compliance boundary distance), and a reference site were compared using biological and sediment chemistry metrics to measure organic enrichments and environmental degradation. Pre-cage installation sampling to establish baseline benthic conditions was conducted in July 2003 as part of the Maine Department of Marine Resources Finfish Aquaculture Monitoring Program (FAMP) using the same methodology used in the project. Three subsequent benthic samplings were carried out over the course of the growing cycle: November 2003, May 2004, and November 2004. On each occasion triplicate samples were collected for measurement of redox potential, sulfide (beginning in November 2003), total organic carbon, granulometry, and benthic infauna analysis for abundance, species richness, relative diversity, and dominance by *Capitella capitata*.

The site was visited three times, approximately one week after the benthic sampling was carried out, for fish health and exposure sampling. Observation/sampling consisted of visual inspection of fish for clinical abnormalities, collection of blood and fecal samples, evaluation of mortality and growth records and communication regarding any adverse health events. Stable $\delta^{15}N$ and $\delta^{13}C$ isotope ratios analysis was performed on fish blood, feces, mussel tissue, barnacle tissue, feed and sediment.

Water quality measurements were made in August 2004 within each study cage by collecting water column profiles of dissolved oxygen, temperature, and salinity and samples were taken for analysis of 5-day bio-chemical oxygen demand (BOD_5). LiftUp® effluent was collected in September 2004 from two cages following 5 days of non-operation (representing a "worst case" condition) for analysis of BOD_5, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and Total Coliforms (TC), the latter as a surrogate for pathogens.

Findings

Over the course of the project, LiftUp® appeared to offer some marginal environmental benefit although that benefit was only statistically significant early in the project. In general, where sediment chemistry results exceeded the MePDES warning thresholds, LiftUp® indicated lower organic enrichment, although high variability obscured statistical differences. Biologically, LiftUp® tended toward greater biological diversity, species richness, and lower overall abundance. We believe that differences may have been stronger were it not for several factors, some controllable and others not.

An observed shift in sediment grain size toward coarser material at all sample stations, including the reference stations, was unexpected and uncontrollable, yet we believe important in affecting results. Sample results on any single sample event indicate that bottom sediments are relatively homogenous making it unlikely that this coarsening trend was an artifact of sampling different populations of sediment. Furthermore, we do not believe that a venturi effect under cages was responsible since sediments at the reference station also coarsened. Rather, we suspect natural oceanographic processes are at play. This part of the Maine coast is exposed to severe storms and periodic strong currents. Most coarsening occurred between July 2003 and November 2003 and again between May 2004 and November 2004. The "scouring" that presumably coarsened the grain size may have also been responsible for muting environmental differences between LiftUp® and non-LiftUp®. It is also possible that currents increased the radius of the depositional area under each cage so that the influences from two cage treatments were overlapping. This is suggested by results from the 30 meter stations where most enrichment parameters responded.

Regardless of mechanism, the change in grain size and the influences of such changes on the benthic community structure over time have important regulatory implications. Compliance with the MePDES permit is based on a comparison of monitoring results to "baseline" and/or reference conditions as one means of determining whether or not conditions are a result of natural or human activity. The sediment coarsening demonstrates that "baseline" conditions are ephemeral. Use of baseline conditions alone to draw conclusions regarding cause and effect in marine systems for this industry in particular can be misleading. This emphasizes the need to better understand spatial and temporal variability of all variables before incorporating them into regulatory schemes.

The plume of dissolved and particulate material resulting from LiftUp® surface discharge did not raise environmental concerns due to its brevity (<100 seconds), very small area (5m x 10m oval), small volume ($2.1m^3$) and intermittent frequency (1-3 times per week). However, the plume did raise concerns about fish health. While we did not see differences in fish health parameters between LiftUp® and non-LiftUp® cages, at sites where disease pathogens or parasites are known, it would certainly be prudent to develop a method that minimized, or avoided altogether, release of material to the water column adjacent to or upcurrent of other cages. Rather than conducting additional work to investigate whether exposure to the plume affects fish behavior, reduces feeding or causes some off-flavor, given the small volume, it may be more practical to simply contain the "first flush," for removal off-site.

Few significant differences in fish health parameters were noted between LiftUp® and non-LiftUp® diver-based systems. The only parameter that varied significantly ($p<0.05$) was fecal $\delta^{15}N$ composition, which ran higher in the cages lacking Lift-up® systems. The paucity of statistically significant differences in fish health meristics suggests that the current best management practice of mortality removal by diver is just as good, from a fish health standpoint, as that achieved by the LiftUp® system. However, we believe difference may have been obscured because divers were ultimately needed to enter LiftUp® cages more frequently than planned. Substantial variation in historical circumstances between different cohorts of fish (involving two different hatcheries and two different smoltification strategies) required statistical accounting of cage variation, limiting the power of our study design to detection of differences that were only large in effect. Once operational problems specific to the nature of our application of LiftUp® are resolved, a future study involving more cages and/or more sites may detect more subtle differences between treatments.

Animal stable isotope compositions typically approximate the signatures of their diet: $\delta^{15}N$ is usually about 3-5 ppt heavier than diet; $\delta^{13}C$ is usually 0-1 ppt heavier than diet. Though not statistically significant, the $\delta^{15}N$ of the salmon from diver-based cages was consistently higher than that of salmon from LiftUp® cages. Coprophagy and/or consumption of suspended carcasses fragments by the fish, or indirectly by zooplankton or other organism entering a food web leading to the salmon, could alter the values of salmon $\delta^{15}N$. However, the statistically significant difference between fecal compositions of salmon from LiftUp® vs. diver-based systems, as well as a consistently disproportionate enrichment of $\delta^{13}C$ of salmon tissue relative to that of the fed feed pellets, raises the possibility that the salmon were differentially supplementing their diets with native faunal organisms. The mesh size of the LiftUp® conical bottom panels was finer than that of traditional netting, which could possibly limit the entry of britt herring or krill or other free-ranging fauna organisms that the salmon might be consuming. Future studies may benefit from further evaluation of impacts of LiftUp® systems on feed supplementation and nutritional requirements.

B. If significant problems developed which resulted in less than satisfactory or negative results, they should be discussed.

Conducting an experiment within a business enterprise poses a unique set of challenges and expectations that must be reasonably accommodated. Day-to-day duties at any net-pen farm on the Maine coast require continuous adaptation to ever-changing conditions. Storms, personnel changes, fish health, situations at other sites, and bottom line economic considerations redirect personnel away from the needs of any experiment toward higher priorities. This project was designed, incorporated, and conducted within the normal constraints of a commercial salmon farm where a farm managers' primary obligation is to fish husbandry. From the outset, we understood that record keeping and operation and maintenance of LiftUp® equipment would be secondary to the demands of fish husbandry. In this respect, this project may have been a more realistic test of the technology than an academic study conducted within a strictly controlled environment.

One event had especially serious consequences to this study. The project began in the middle of a federal lawsuit that forced the sale of Atlantic Salmon of Maine, Inc. half way into the project. Although the new owner indicated his desire to complete the project, the real effect of direct and indirect court imposed constraints, including the requirement to fallow half the company's net pens sites, closing a state-of-the-art fish processing plant, and laying off more than 60% (40-50) of its employees, resulted in severe changes in personnel, operations, and management. Most significantly, the reduction in personnel meant that daily work demands of remaining farm employees allowed less time for operation, maintenance and detailed record keeping than we initially planned. While one could easily have justified abandoning this project, much to their credit, the new owner and personnel maintained their commitment to completing the project to the best of their ability.

LiftUp® is designed as a mortality collection device to benefit fish health by reducing the use of divers inside cages and by isolating carcasses and potentially infectious material from the water column during removal from the cages. The personnel reductions prevented operation of LiftUp® at optimal frequencies and that in turn led to clogging of the system and the need for divers to clear the intakes of debris and twists in the "flat lay" pipe. It also became apparent that the slope of the conical LiftUp® net of cages located in the shallower portions of the lease was insufficient to allow feed, feces and other debris to slide and roll to the suction unit. In those cages, the suction unit had a limited zone of influence leaving a ring of material resting on the net bottom that needed to be manually disrupted and directed toward the suction unit by a diver. According to the site operator, to hold an economically feasible number of fish and achieve an effective cone angle, the minimum site depth for a LiftUp® cage is 65-70 ft. at mean low water.

Anecdotally, operations staff thought that divers may have been deployed almost equally between LiftUp® and non-LiftUp® cages, either to unclog the suction unit, to move material toward the suction mouth, and during winter to collect mortalities, thereby reducing the intended benefit of LiftUp® and subjecting the fish in both LiftUp® and non-LiftUp® cages to similar levels of stress.

C. Description of need, if any, for additional work.

In view of the problems encountered with clogging and freeze-up using the current pneumatically-driven LiftUp® system, additional work may be warranted to investigate possible alternative approaches. One possible alternative to prevent clogging might be to retain the fine-mesh bottom nets to collect waste, but to substitute a moderate-duty grinding pump, also known as a "trash pump", for the air compressor of the pneumatically-driven LiftUp® system. Such a pump would have the capacity to breakup and grind potentially clogging or blocking material and would not be susceptible to freeze-up. However, deploying and recovering the pump and discharge hose into the center of each pen would present certain technical challenges; additionally, the entire device, pump and hose, would need to be thoroughly cleaned between deployments to ensure against disease transmission from cage to cage if infection were present on the site. Although such a system might prove effective in surmounting some of the clogging and freeze-up problems encountered with LiftUp®, the destruction of mortalities would make inventory tracking virtually impossible; some manner of separating mortalities from waste would therefore be required and such an approach might continue to required diver mortality collection.

To address fish health concerns resulting from the discharge, the collection and containment of the most concentrated portion of the discharge for offsite disposal or processing might be easily and affordably accomplished, but feasible methods of accomplishing this might also be investigated.

VII. Evaluation

A. Describe the extent to which the project goals and objectives were attained.

1. Were the goals and objectives attained? How? If not, why?

All of the environmental assessment goals of the project were met. First, the usefulness of LiftUp® as a means to reduce environmental impact under commercial salmon pens appears possible, although not under all circumstances and sites and provided that certain modification are made to the equipment used. Second, the assessment of the potential water quality impacts caused by LiftUp® operation clearly show that the discharge, due to its brevity, small volume and consequent very small area of influence, and intermittent frequency does not result in any significant impact; however, the plume does raise concerns about fish health since it could serve to spread disease if diseased fish were present in cages at the site. Thirdly, the assessment of the effect of LiftUp® on fish health showed no significant differences in stress levels between fish in either LiftUp® and non-LiftUp® cages.

The goal of determining the economic feasibility, or more specifically an economic benefit, of using LiftUp® was confounded by the constraints on personnel to fully track the costs associated with the use of LiftUp® as well as the problems encountered with the clogging of the suction unit that essentially eliminated the cost savings anticipated from the reduced need for diver entry into the cages.

2. Were modifications made to the goals and objectives? If so, explain.

Although the goals and objectives remained unchanged throughout the project, certain changes were made in the experimental design. First, the final arrangement of the LiftUp® and non-LiftUp® cages rendered the originally proposed water sampling design of water column profiling at the 30 meter distant station somewhat irrelevant, since the staggered cage arrangement would not have allowed distinction between LiftUp® and non-LiftUp® cage influences. Consequently, the water quality measurement emphasis was shifted to the cages themselves, i.e. direct measurement within the cages. Additionally, measurements were added to determine the quality of the effluent discharge to ascertain the potential environmental consequences of direct discharge versus collection; measurement of the "first flush" suggests the feasibility of containing the bulk of the collected material for either diffuse discharge off-site or storage and processing.

The second change to the sampling plan was the incorporation of sulfide as a measured parameter. At the time the project was proposed, the Maine Department of Environmental Protection was considering, but had not yet adopted, sulfide measurement as a parameter for inclusion in its monitoring requirements. After the project began, the DEP did adopt sulfide measurement as a monitoring requirement and the parameter was therefore incorporated into the suite of parameters measured by the project.

B. Dissemination of Project results:
Explain, in detail, how the project results have been, and will be, disseminated.

A presentation, centered on a PowerPoint presentation, was given at the Maine Aquaculture Association's Bay Management meeting on January 25, 2006 by the co-investigators, Chris Heinig (MER), John Sowles (MDMR), and Lori Gustafson (USDA) and was followed by a 1-2 hour discussion with industry representatives of the results and potential modifications that might be made to improve the usefulness of the basic principle of waste collection and removal to mitigate benthic impacts.

The final technical report will be available in pdf format, along with a copy of the PowerPoint presentation, on the Maine Department of Marine Resources Aquaculture web site and the MER Assessment Corporation web site.

APPENDIX A

Evaluation of Lift-Up® system in the mitigation of environmental impacts and fish health in net-pen aquaculture

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(Available as a PDF file: LiftUp031206cmprssed.pdf)